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PARTICLE TRACKING VELOCIMETRY OF A GLIDING ARC DISCHARGE

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A 35 kHz AC gliding arc discharge at atmospheric pressure is generated between two diverging electrodes and extended by an air flow. The gas flow velocity is measured by particle tracking velocimetry (PTV) while the moving velocity of the plasma column of the gliding arc discharge is measured by analyzing the movie taken by a high-speed camera. The two-dimensional velocity vector of the gas flow and of the gliding arc in the imaging plane was determined.

1 Introduction

Gliding arc discharges have been developed to create non-thermal plasma at atmospheric pressure for pollution control [1], surface treatment [2] and combustion enhancement [3]. A discharge is ignited at the narrowest gap between two diverging electrodes, and the plasma column is extended by a gas flow. Dynamics [4, 5], physical characteristics [6] and chemical mechanisms [7] involved in the gliding discharge have been widely studied and theoretical models [8, 9] have been built to explain the behavior of gliding arc discharges. According to “the heat string model”, the plasma column moving velocity of the gliding arc and gas flow velocity are essential parameters governing the power dissipated per unit length, the maximum length, radius of the plasma column and cooling efficiency [9].

In previous studies, the flow velocity was measured either by tracking particles illuminated by a laser sheet [6] or by using a Pitot tube [9] while the plasma column moving velocity was calculated from two consequential 2D images. However, the additional equipment (the external illumination source or the Pitot tube) adds experimental complexities, and the Pitot tube even disturbs the flow. In the presented study, particle tracking velocimetry of a gliding arc was performed without involving external illumination sources. The bright plasma column itself was used as illumination source, and the movements of the plasma column and the seeding particles were

simultaneously tracked by a high-speed camera. The gas flow velocity and plasma column moving velocity, and consequently the slip velocity, were determined.

2 Experimental setup

The experimental setup is shown schematically in Fig.1. A gliding arc discharge at atmospheric pressure is generated between two diverging stainless steel electrodes using a 35 kHz AC power generator (Generator 9030E, SOFTAL Electronic GmbH, Germany). The hollow electrodes with 3 mm outer diameter are internally water-cooled. The narrowest electrode gap is about 7 mm. A total air flow of 17.5 standard liter per minutes (SLM) controlled by a mass flow controller (MFC) was split into two parts: one was controlled by a second MFC at 16 SLM while the other was passed into a particle seeder filled with TiO_2 particles of $\sim 3 \mu\text{m}$ diameter. The seeding particles closely follow the local gas flow and thus indicate the gas flow velocity. The total air flow with particles then blows the generated plasma column along the electrodes.

A high-speed camera (Fastcam SA-X2) was used to track both the movement of the plasma column and the illuminated seeding particles (nearby the bright plasma column). A Nikon camera lens ($f = 75\text{-}150 \text{ mm}$) was mounted on the high-speed camera. In order to track the particles in high-temporal resolution, the frame rate for the high-speed camera was set at 100 kHz, and the exposure time was set as $8.32 \mu\text{s}$.

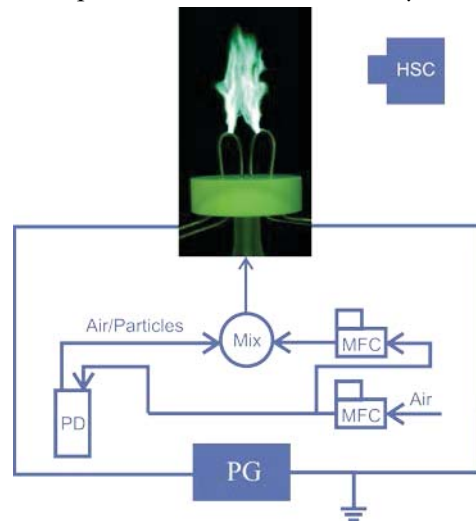


Figure 1: Schematic diagram of experimental setup. HSC: high-speed camera, MFC: mass flow controller; PD: particles seeder; PG: power generator.

3 Results and discussion

Fig.2 shows five images of the gliding arc together with the seeding particles, indicating the movement of the arc plasma column and the gas flow. The time interval between the images is $200 \mu\text{s}$. The particles are illuminated by the bright plasma column, and the movements of the gliding arc as well as the seeding particles, located in the vicinity of the gliding arc, can be tracked by the high-speed camera. From displacement of the particles and the gliding arc in the sequential images, the two-dimensional velocity vectors of the particles and the gliding arc in the imaging plane can be calculated. Note

that only few particles quite close to the plasma column can be seen though many more particles are seeded into the gas flow.

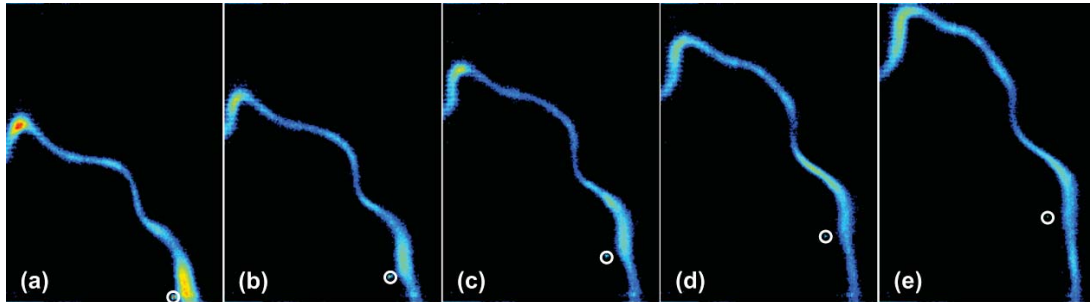


Figure 2: Movement of the gliding arc with a seeding particle tracked by the high-speed camera. The particle was marked by a circle. (a) t_0 ; (b) $t_0 + 200 \mu\text{s}$; (c) $t_0 + 400 \mu\text{s}$; (d) $t_0 + 600 \mu\text{s}$; (e) $t_0 + 800 \mu\text{s}$;

Fig.3 displays the superimposed photo of the five frames shown in Fig.2, showing the movement of the plasma column and the seeding particle. The arc movement is represented by tracking several local points in the plasma column. The top of the gliding arc and the part close to the seeding particle are tracked. The arrows show the direction of velocity vector, and the length shows the vector magnitude.

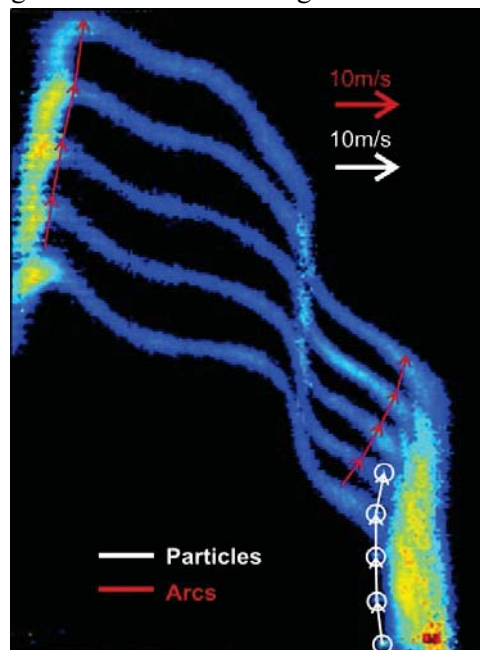


Figure 3: Tracking of plasma column and the seeding particle. The particle is marked by circles and the arc movements are tracked using the top of the arc and the part close to the seeding particles.

Fig.4 shows the plasma column moving velocity and gas flow velocity. The color bar indicates the magnitude of velocity vector. It is found that the velocity in the outer region of the jet is 6 – 7m/s. The plasma column moving velocity is position dependent. At the

top of the arc close to the center of the jet, the plasma column moving velocity is about 8 – 10 m/s. In the outer region of the jet close to the seeding particle, the plasma column moving velocity is about 5 – 6 m/s. It is reasonable to use the velocity of the arc close to the seeding particle for calculating the relative velocity with respect to the gas flow. The relative velocity between the gliding arc and the gas flow is about 1 – 2 m/s, so the gas is up to 20% faster than the plasma column. This slip velocity affects the cooling efficiency [9]. The relative slip velocity of 10-20% is consistent with previously reported values [6, 9].

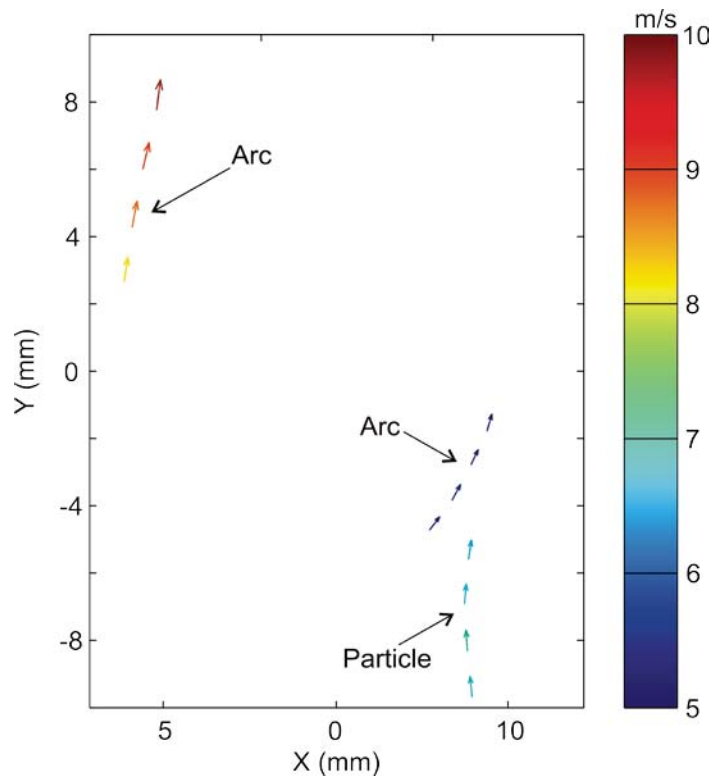


Figure 4: Plasma column moving velocity and gas flow velocity.
The color bar shows the magnitude of the velocity vector.

4 Conclusions

In conclusions, two-dimensional plasma column moving velocity and a local gas flow velocity were determined by particle tracking velocimetry directly using the bright plasma column as illumination source. The slip velocity of arc plasma column with respect to the gas flow velocity is about 1 – 2 m/s corresponding to about 20% of the local flow velocity, suggesting effective cooling of the plasma column by the gas flow. Note that the gliding arc acts like a string, dancing in three-dimensional space. Therefore, three-dimensional particle tracking velocimetry (PTV) will give more accurate results. It is possible to achieve 3D PTV with advanced reconstruction algorithm using two projections acquired by two high-speed cameras [10] .

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